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E. L. Sheninger

L. W. Lu

LEHIGH UNIVERSITY INSTITUTE OF RESEARCH

PLASTIC DESIGN OF MULTI-STORY FRAMES

PROPOSAL FOR TESTS OF NON-SWAY BEAM-AND-COLUMN SUBASSEMBLAGES

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1. INTRODUCTION

Currently, the use of plastic design is limited to simple or continuous beams, one and two-story rigid frames, and beams in the lower stories of a multi-story frame -- provided that the columns are designed elastically.[1*] But enough research has been completed in recent years to supply the necessary information to extend the use of plastic design beyond these restrictions.[2,3,4,5,6] The problem of beam-column instability, which has hampered this extension in the past has been studied a great deal, and it is now possible to predict accurately the behavior of beam-columns subjected to loads that would cause instability.

There have been many tests conducted on beam-columns in single curvature as shown in Fig. 1a; quite a few have included beams (Fig. 1b) to show the effect of rotational restraints on the strength of the beam column; a few tests have been run on beam-columns bent in double curvature (Fig. 1c). Most of the above mentioned tests included an axial force on the columns of 0.6 P_y or less, and only a few have been loaded as high as 0.8 P_y.[2]

But there have not been any tests conducted on full-scale, complete beam-and-column subassemblages with loads applied directly to the beams. The full-scale, complete subassemblage considered in this

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*Superscripts refer to references cited at the end of this report.

proposal consists of two beams framing into three sections so as to simulate a portion of a three-story bent in a multi-story frame. (Figs. 2 and 3).

It is known that a subassemblage will fail at loads that are greater than the ultimate strength of any one of its individual members, because of the rotational restraint offered by each member to the joint. This increased strength has also been noted in a multi-story frame and is, in fact, the reason why a frame may be designed by assuming that it is composed of a series of subassemblages.

The subassemblage is a useful tool in the design of multi-story frames. It reduces a complex frame to only a few variables, and allows a very rapid design. As with a subassemblage, a multi-story frame will be stronger than any one of its respective subassemblages.

The purposes of the proposed subassemblage tests are four: First, to study the strength of beam-and-column subassemblages that have moments applied to the joints through laterally loaded beams, and to observe their failure behavior; second, to study the behavior of beam-columns under high axial loads; third, to study the effect of an added column on the moment carrying capacity of the heretofore beam-to-column joint; fourth, to provide experimental confirmation of the design procedure developed in Chapter 11 of Reference 7.

2. PROPOSED TEST PROGRAM

2.1 Test Arrangement

The proposed series of tests will consist of a total of four subassemblage specimens made of ASTM A36 steel: two in single curvature -- typical of an interior column in a frame under checkerboard loading (Fig. 2); and two in double curvature -- typical of an exterior column in a frame under full loading (Fig. 3). Each of these two sets will include one test with columns that have a strong axis slenderness ratio of $h/r_x = 35$ and one with $h/r_x = 30$ (Fig. 7). All four tests in the series have been designed to withstand axial loads of from $0.8\ P_y$ to $0.9\ P_y$. These relatively high axial loads are quite common in the lower stories of a tall multi-story frame. It is at these high axial loads that instability has its greatest effects. First the plastic moment is reduced considerably because of the interaction of moment and axial force; and second, the column becomes unstable at a moment such less than the reduced plastic moment of the section.

2.2 End Restraints

The ends of the columns and the ends of each beam are pinned (Figs. 2 and 3). Pin-ended members may not simulate the actual conditions in a multi-story frame, but exact simulation is usually not necessary. It is possible to design columns with any end restraints by using the proper moment-rotation curves.[8] Thus, it is possible to theoretically predict the behavior of the subassemblage, and then compare the predictions with the test results. In the case of double curvature columns (Fig. 3), the approximate center of the upper and lower columns is an actual pin-ended restraint, because this is the point of contraflexure.

2.3 Load Application

Figure 4 shows the loading arrangement for the subassemblage with columns bent in single curvature. First, an axial load will be applied to the columns with the 5 million pound universal testing machine. Vertical loads will then be applied to each beam at the quarter points, using one gravity load simulator for each beam and a spreader beam to divide the load into two. Compression in the upper column will be about 0.81 P_y. At joints B and C, a shear will be transmitted to the columns from the beams, so the axial loads will increase to about 0.84 P_y and 0.86 P_y in the middle and lower columns, respectively.

The subassemblages with double curvature columns (Fig. 5) will be loaded in much the same manner as the single curvature case with only one difference in the apparatus used to apply the loads. Instead of using only one simulator per beam, it is now necessary to use one for the lower beam and two (one on each side of the lower beam simulator) for the upper beam. In this way, the two outside simulators can pull the upper beam vertically downward eliminating the possibility of a horizontal component due to load application from outside of the plane of the two beams.

2.4 Predicted Results

All four tests have been designed so that failure is expected to occur simultaneously at both joints. As the load is applied to the beams (axial compression already existing in the columns), the plastic hinges will form first in the beams. If the columns have not failed at the time of the beam mechanism, additional axial load will then be applied in order to cause them to fail.

The maximum strength of the subassemblages has been predicted. Figure 6a shows the moment-rotation curves of both joints in test SC-1. As shown, the predicted maximum moment for joint B is higher than for joint C. The reason for this difference is that in order to ensure failure of both joints simultaneously, without using spliced columns, it was necessary to reduce the applied moment at the joint with higher axial loads. Figure 6b shows the moment rotation curves for both joints in test DC-1. Comparison of the curves for SC-1 (single curvature) and DC-1 (double curvature) show that, in the single curvature test, there is only a limited amount of rotation capacity -- both joints reach maximum moment and then drop off. But in the double curvature test, there is a considerable amount of rotation capacity -- the joints reach maximum moment, retain that moment for an additional rotation, and then slowly drop off. The maximum moment for each joint in each of the four tests is listed in the table in Fig. 6. The letter notation used to designate the members refers to Figs. 4 and 5. The lengths listed are in units of feet and the maximum moments in units of kip-ft. In the single curvature tests, a decrease in the h/r_x ratio was compensated for by raising the P/P_y ratio rather than reducing the member sizes; no such compensation was required in the double curvature specimens, since double curvature is little affected by instability, and a decrease in h/r_x cannot improve on a situation where the effective reduced plastic moment is negligibly less than the full plastic moment.

3. SUMMARY

Tests have been conducted in the past on beams, columns, and beam-columns. It is now time to put all the components together in a subassemblage to show that the theory developed to predict the behavior of the individual components can be used to predict the behavior and strength of the entire system.

The subassemblage tests have been designed according to the procedure outlined in Chapter 11 of Ref. 7. Thus, the results of these tests will be used to verify the proposed design procedure.

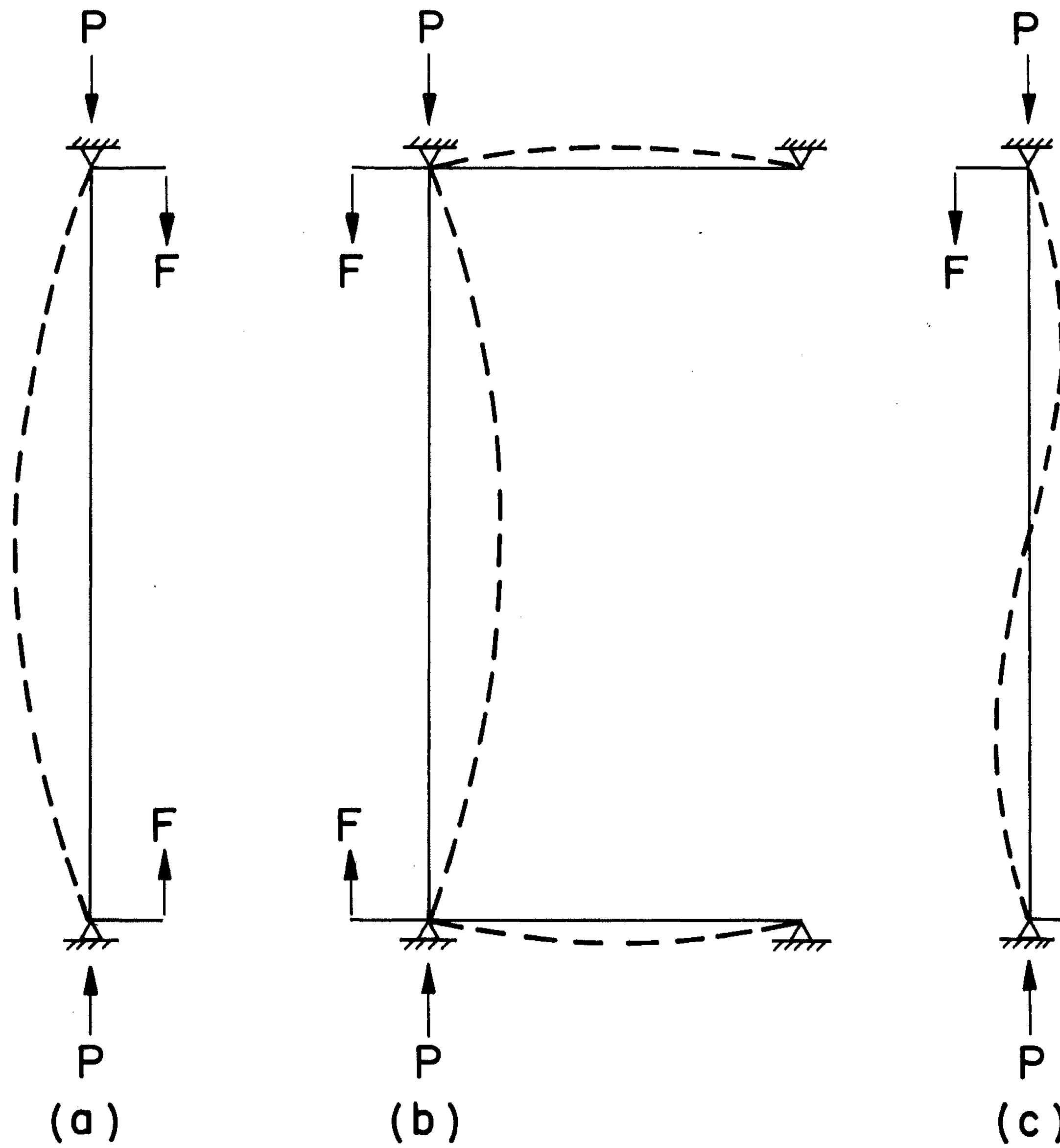

Fig. 1 Previous Beam-Column Experiments

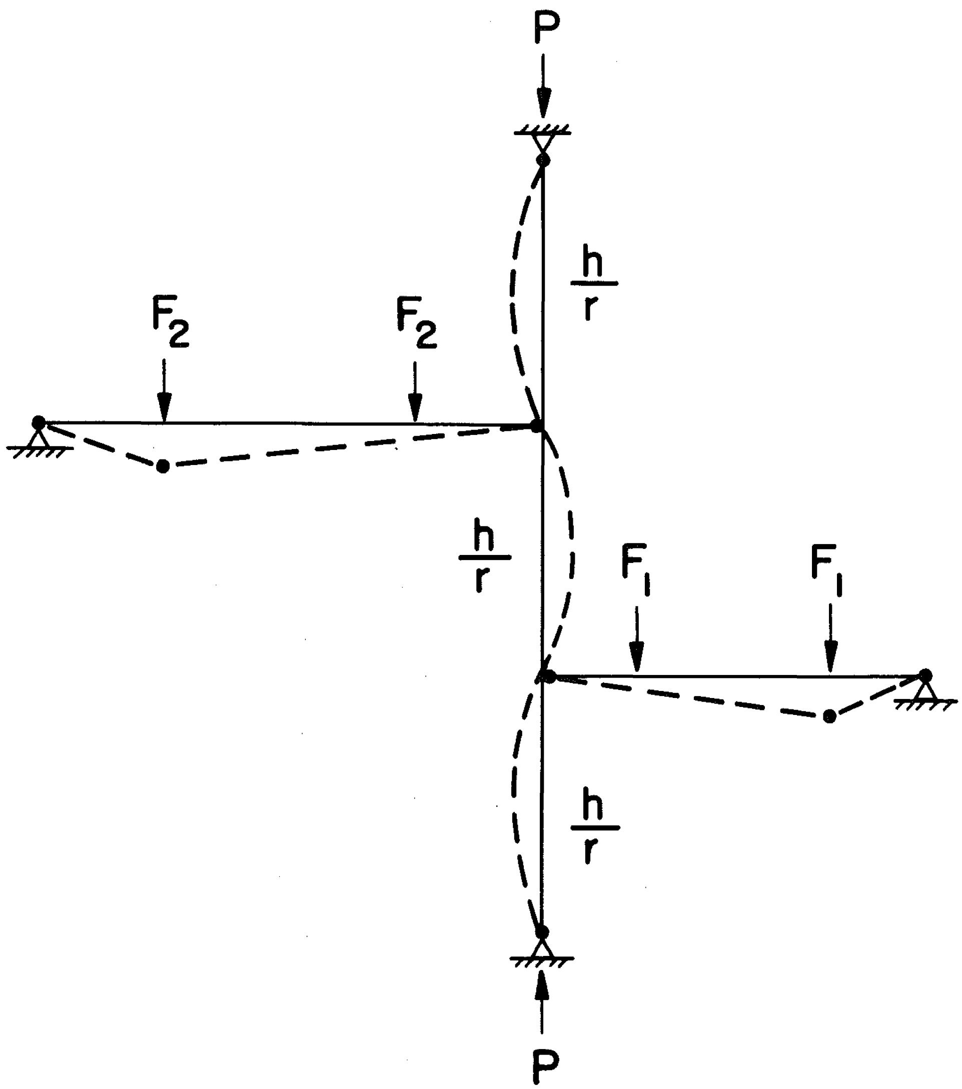

Fig. 2 Complete Subassemblage With Columns in Single Curvature Bending

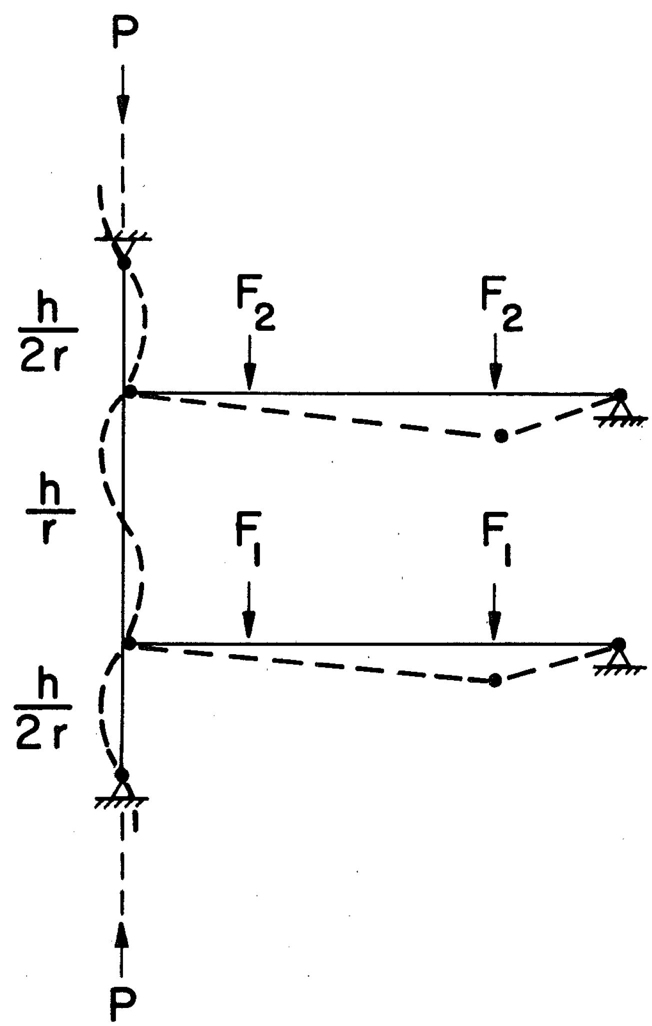

Fig. 3 Complete Subassemblage With Columns in Double Curvature Bending

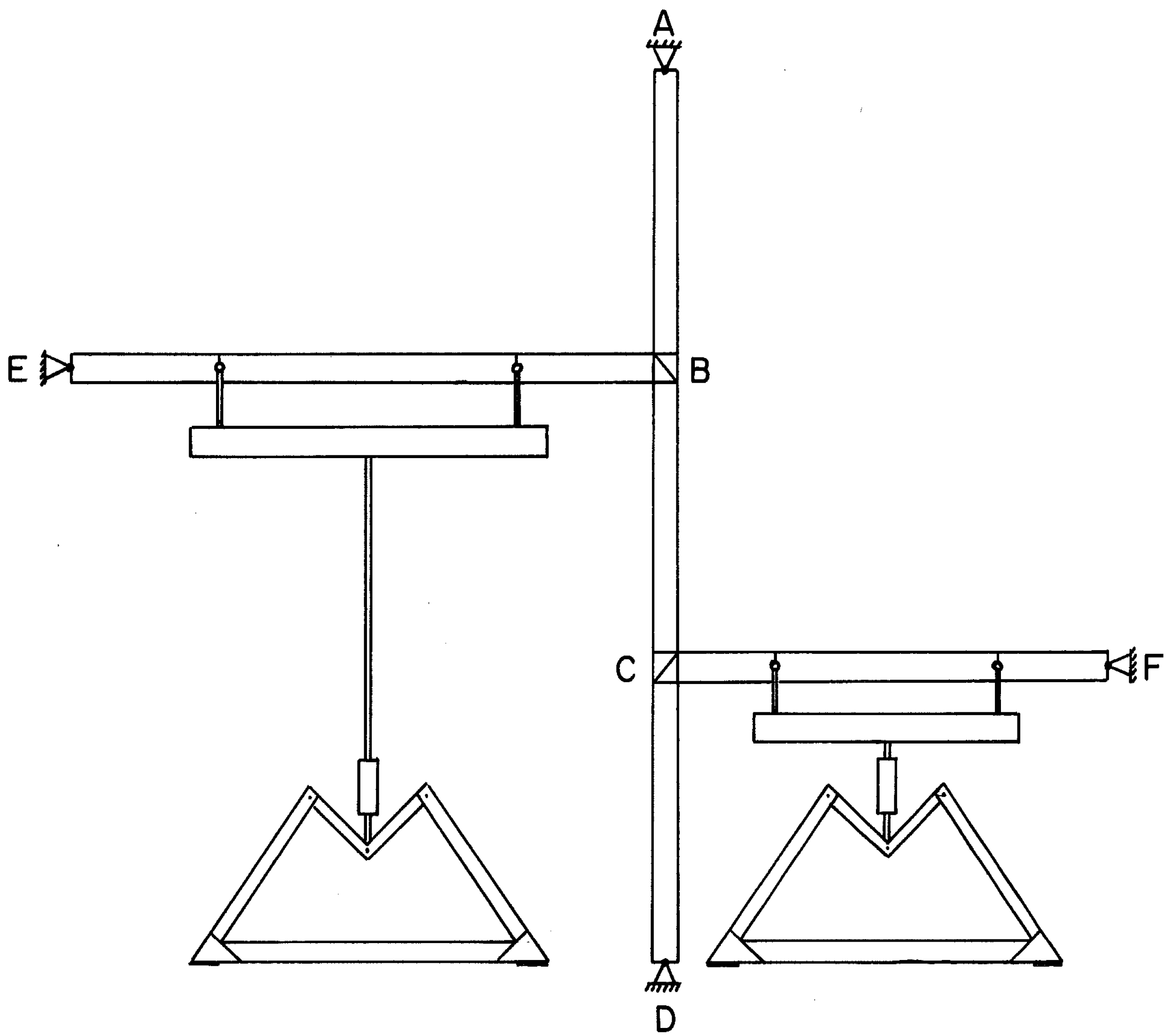

Fig. 4 Test Setup for Subassemblage with Columns in Single Curvature Bending

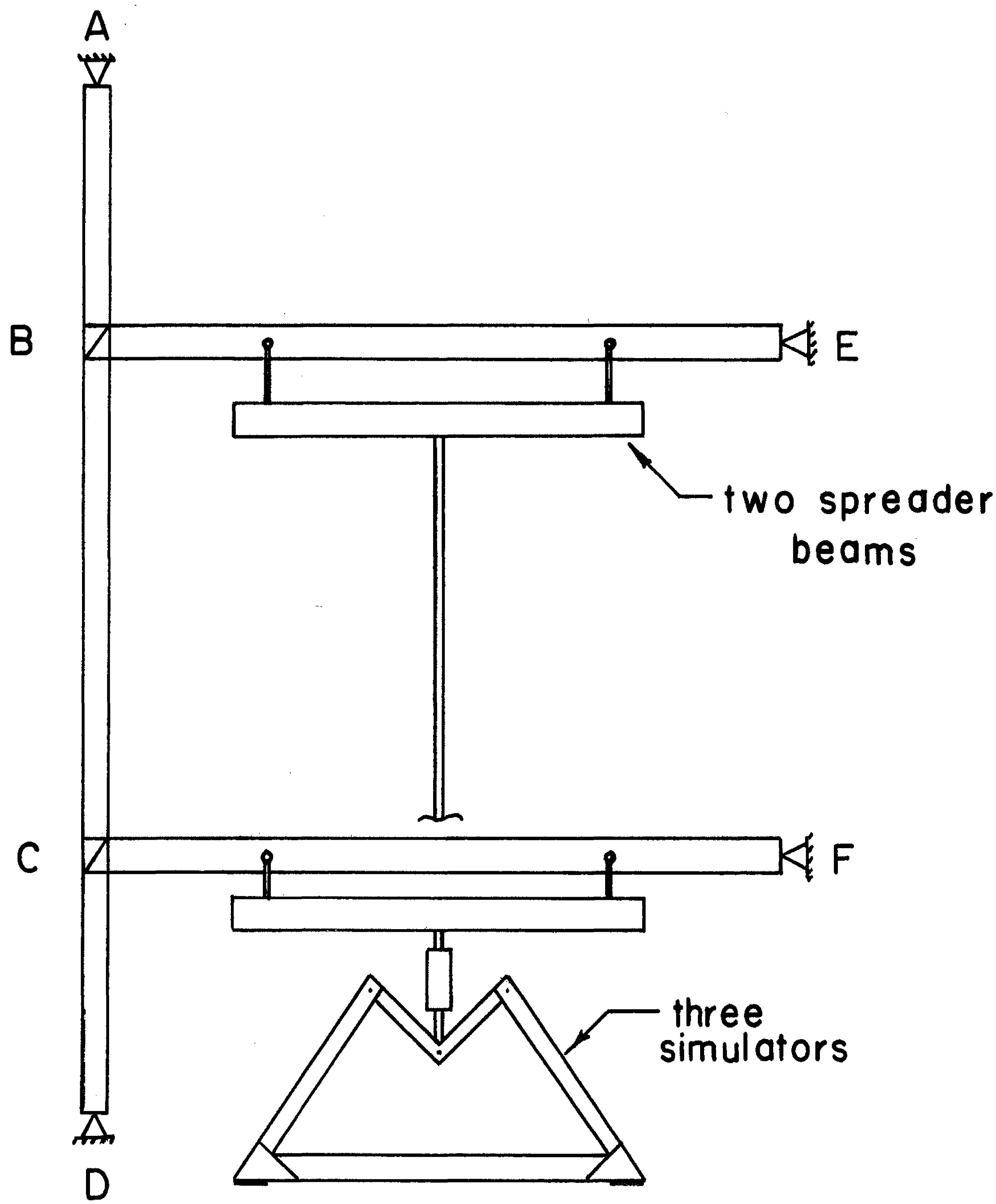

Fig. 5 Test Setup for Subassemblages with Columns in Double Curvature Bending

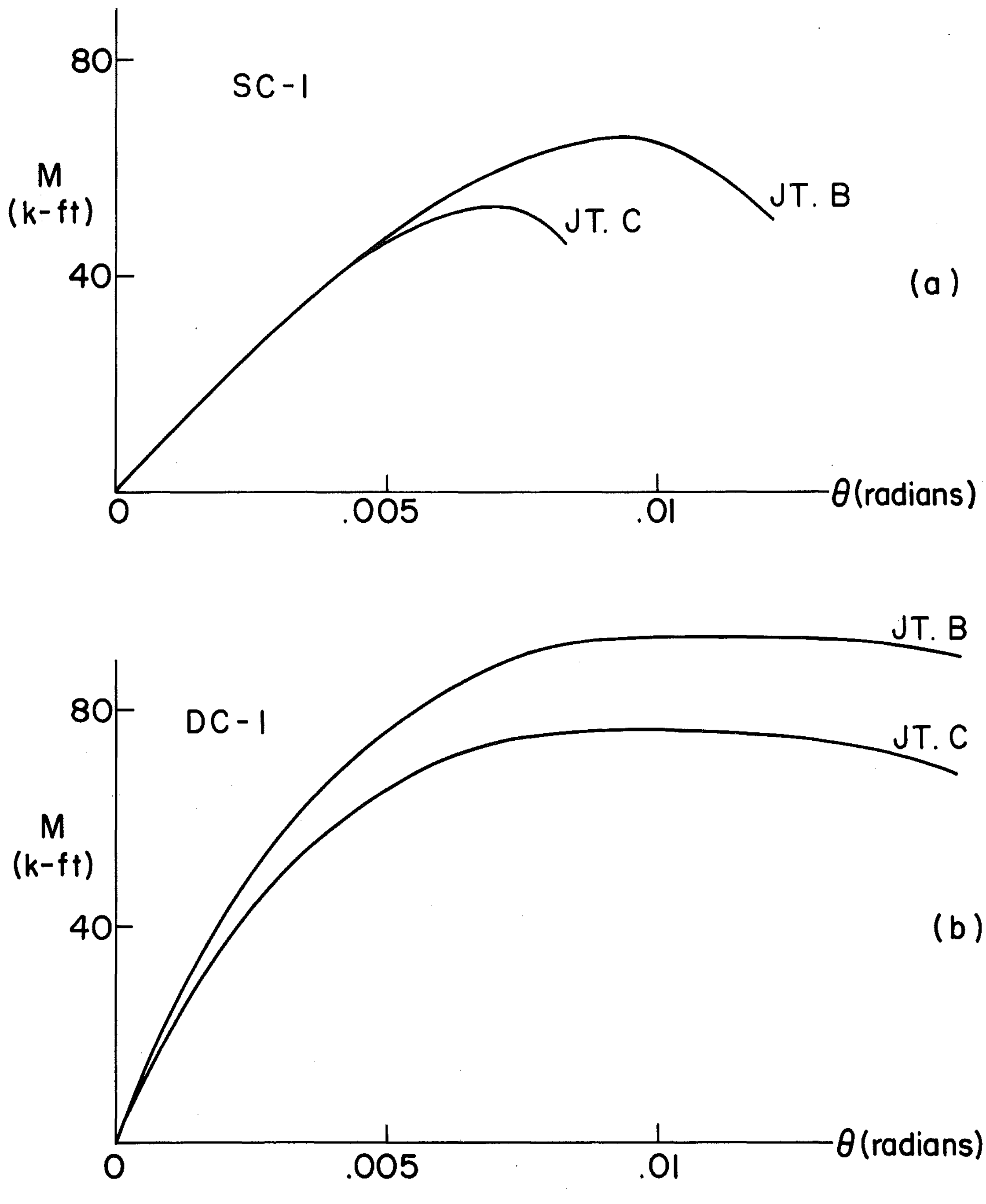

Fig. 6 Predicted Moment-Rotation Curves

Spec No.		Columns			Beams		Joints	
		AB	BC	CD	BE	CF	B	C
SC-1	Shape	8 WF67	8 WF 67	8 WF67	10 B 17	8 B15	—	—
	Length	10.8	10.8	10.8	20.0	15.0	—	—
	h/r_x	35	35	35	—	—	—	—
	P/P_y	0.81	0.835	0.859	—	—	—	—
	Mm	—	—	—	—	—	66.4	51.4
SC-2	Shape	8WF67	8WF67	8 WF67	10B17	8 B15	—	—
	Length	9.3	9.3	9.3	20.0	15.0	—	—
	h/r_x	30	30	30	—	—	—	—
	P/P_y	0.82	0.845	0.869	—	—	—	—
	Mm	—	—	—	—	—	66.7	51.4
DC-1	Shape	8WF67	8WF67	8WF 67	10I 25.4	8WF24	—	—
	Length	5.4	10.8	5.4	20.0	20.0	—	—
	h/r_x	17.5	35	17.5	—	—	—	—
	P/P_y	0.80	0.837	0.868	—	—	—	—
	Mm	—	—	—	—	—	93.2	76.0
DC-2	Shape	8WF 67	8 WF67	8WF 67	10I 25.4	8 WF24	—	—
	Length	4.6	9.3	4.6	20.0	20.0	—	—
	h/r_x	15	30	15	—	—	—	—
	P/P_y	0.80	0.837	0.868	—	—	—	—
	Mm	—	—	—	—	—	93.2	76.0

Fig. 7 Summary of Test Specimens

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